CLEARINGHOUSE FOR FEDERAL SCIENTIFIC AND TECHNICAL INFORMATION CFSTI
DOCUMENT MANAGEMENT BRANCH 410.11

LIMITATIONS IN REPRODUCTION QUALITY

ACCESSION # [illegible]

- [x] 1. WE REGRET THAT LEGIBILITY OF THIS DOCUMENT IS IN PART UNSATISFACTORY. REPRODUCTION HAS BEEN MADE FROM BEST AVAILABLE COPY.

- [ ] 2. A PORTION OF THE ORIGINAL DOCUMENT CONTAINS FINE DETAIL WHICH MAY MAKE READING OF PHOTOCOPY DIFFICULT.

- [ ] 3. THE ORIGINAL DOCUMENT CONTAINS COLOR, BUT DISTRIBUTION COPIES ARE AVAILABLE IN BLACK-AND-WHITE REPRODUCTION ONLY.

- [ ] 4. THE INITIAL DISTRIBUTION COPIES CONTAIN COLOR WHICH WILL BE SHOWN IN BLACK-AND-WHITE WHEN IT IS NECESSARY TO REPRINT.

- [ ] 5. LIMITED SUPPLY ON HAND: WHEN EXHAUSTED, DOCUMENT WILL BE AVAILABLE IN MICROFICHE ONLY.

- [ ] 6. LIMITED SUPPLY ON HAND: WHEN EXHAUSTED DOCUMENT WILL NOT BE AVAILABLE.

- [ ] 7. DOCUMENT IS AVAILABLE IN MICROFICHE ONLY.

- [ ] 8. DOCUMENT AVAILABLE ON LOAN FROM CFSTI (TT DOCUMENTS ONLY).

- [ ] 9.

PROCESSOR: [illegible]

TSL-107-10 64

RESEARCH AND DEVELOPMENT DEPARTMENT

U. S. NAVAL AMMUNITION DEPOT - CRANE, INDIANA

DEPARTMENT OF THE NAVY
BUREAU OF WEAPONS

RDTR No. 45
25 September 1964

RELATIONSHIPS OBSERVED IN COLORED FLAMES

U. S. NAVAL AMMUNITION DEPOT
Crane, Indiana

RDTR No. 45
25 September 1964

RELATIONSHIPS OBSERVED IN COLORED FLAMES

PREPARED BY B E Douda
B. E. Douda

REVIEWED BY E F Stinson
E. F. Stinson, Manager, Research Branch

REVIEWED BY B H Calkins
B. H. Calkins, Manager, Concept Division

The information contained in this document represents the opinions of the Research and Development Department and should not be construed to represent the official policy of the U. S. Naval Ammunition Depot, Crane, Indiana. This document is authorized for external distribution.

SIGNED S. M. Fasig
S. M. FASIG, Director, Research and Development Department

TABLE OF CONTENTS

ABSTRACT

Excitation purity of a sodium-yellow flame was observed to be a decreasing function of the magnesium content in the flare. The chromaticity coordinates representing a wide variety of sodium-yellow, barium-green and strontium-red flares when plotted on a chromaticity diagram appear to take the form of straight lines which converge toward a common point. Several theories are proposed to explain the observations, the convergence point and the intercept point of the convergence line with the chromaticity diagram perimeter.

RELATIONSHIPS OBSERVED IN COLORED FLAMES

1. PURPOSE

The purpose of this paper is to report and discuss observations made during a flare improvement program.

2. BACKGROUND

Pyrotechnic compositions formulated to produce yellow colored flames were being studied in an effort to test some of the color production theories advanced earlier by Douda[1]. During the program it was observed that some of the test results were related to one another in a unique manner. These are the observations that will be presented.

3. EXPERIMENTAL

Test specimens were prepared with formulae as shown in Table I. The color data recorded for the eight batches are shown in Table II.

Table I. FORMULATIONS (Percent by Weight)

	Batch							
Ingredients	1	2	3	4	5	6	7	8
Magnesium	20	40	20	30	25	25	22	20
Sodium Nitrate	55	55	50	65	60	70	63	50
Sodium Oxalate	20	--	20	--	10	--	10	20
Potassium Nitrate	--	--	5	--	--	--	--	--
Potassium Perchlorate	--	--	--	--	--	--	--	5
Binder Solution	5	5	5	5	5	5	5	5

Table II. COLOR DATA (Arithmetic Mean)

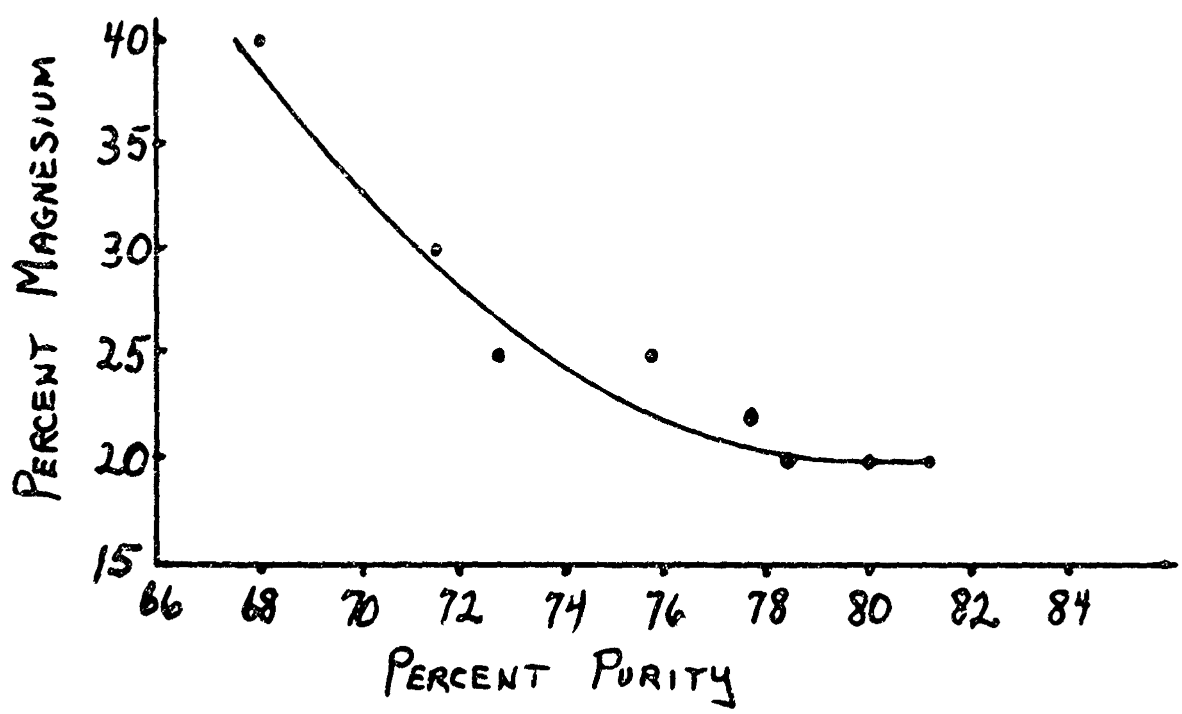
	Batch							
Attribute	1	2	3	4	5	6	7	8
Dominant Wavelength (mμ)	590	588	591	587	587	587	590	591
Purity (%)	81	68	80	71	76	73	78	78

4. OBSERVATIONS

a. Magnesium Content vs. Excitation Purity

A relationship was observed between percent excitation purity and percent magnesium in the formula as shown graphically in Figure 1.

Figure 1

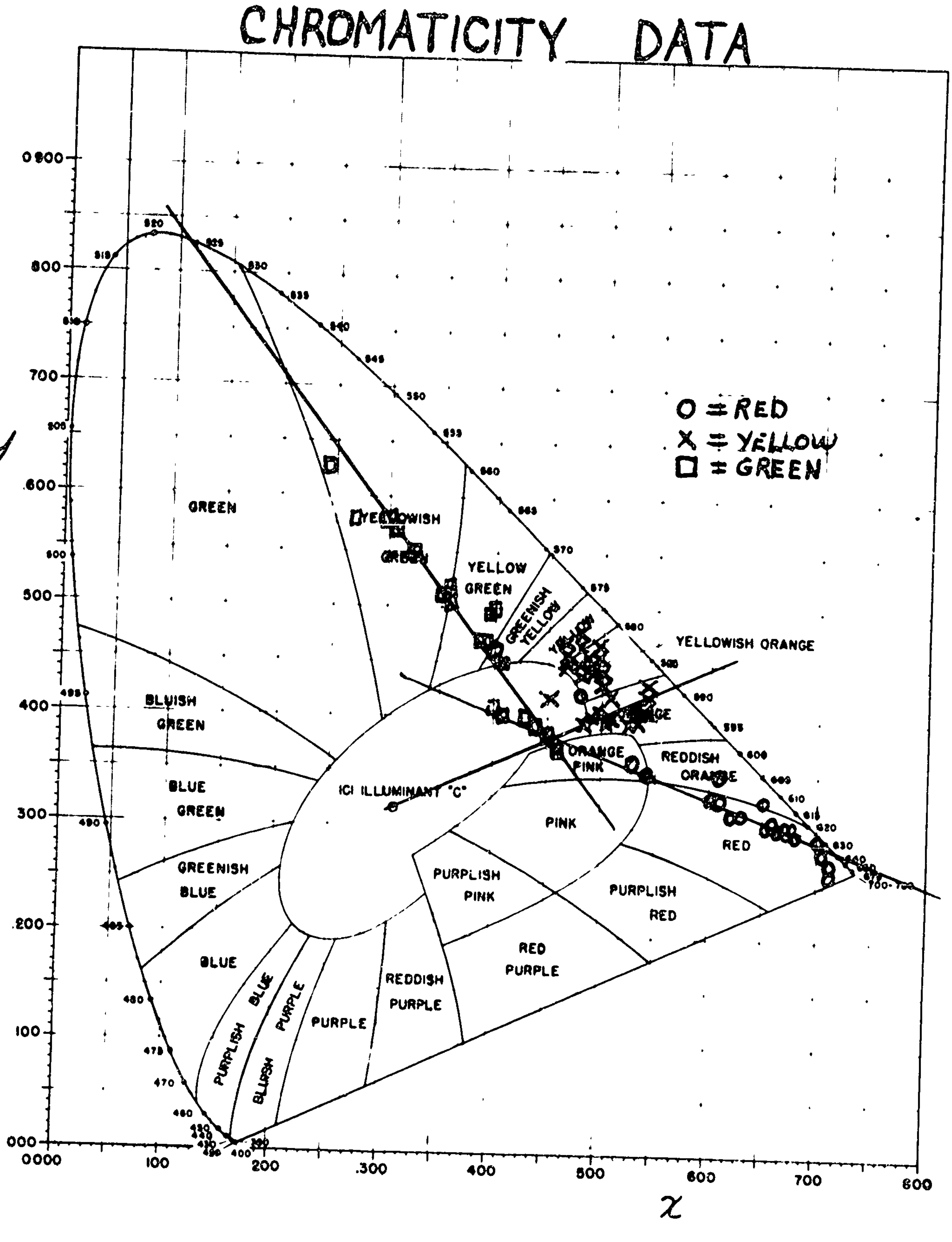


The trend of decreasing purity with increasing magnesium content suggests the formation of an emitter which is a compound of magnesium, such as magnesium oxide. This suggestion is made because of the apparent dependence of the purity upon the quantity of magnesium in the formula. On the other hand, the relationship between magnesium content and excitation purity may be the result of changes in flame temperature. As the magnesium content increases, the flame temperature may be increasing thereby causing a proportionally greater emission increase in the blue region than at other wavelengths. As described by Barrow and Caldin[2], the increase in blue emission will cause a large reduction in excitation purity. In addition, during a study of green flames, Douda[3] observed that blue energy and BaO emission combine to cause purity reduction as an increasing function of temperature. As a result of these observations, it can be theorized that the relationship between purity and magnesium content is most likely the combination of a temperature effect and emission from a magnesium compound such as the oxide or halide.

b. <u>Color Convergence and Wavelength</u>

(1) As a result of the observed relationship discussed in the preceding paragraph, it was decided to determine if a similar correlation is evident for flares of other colors. In order to study the phenomenon from a different aspect, chromaticity data for green, yellow and red flares were taken randomly from the files and plotted on a chromaticity diagram. In the selection of these data, no regard was made to the flare formula or to the percent of magnesium. From Figure 2, the chromaticity diagram shown on the next page, it is apparent that the points representing each of the three colors of flares converge toward a central location ($x = .455$; $y = .380$). The only ingredient that these flares have in common is the magnesium fuel. That being the case, it is hypothesized that the point of convergence represents some form of magnesium emission.

Figure 2


CHROMATICITY DATA
O = RED
X = YELLOW
□ = GREEN
y
x
GREEN
YELLOWISH GREEN
YELLOW GREEN
GREENISH YELLOW
YELLOW
YELLOWISH ORANGE
ORANGE
REDDISH ORANGE
ORANGE PINK
PINK
RED
PURPLISH RED
PURPLISH PINK
RED PURPLE
REDDISH PURPLE
PURPLE
BLUISH PURPLE
PURPLISH BLUE
BLUE
GREENISH BLUE
BLUE GREEN
BLUISH GREEN
ICI ILLUMINANT "C"

As evidenced by the discussion concerning magnesium content and excitation purity, it is difficult to separate the temperature effect from the composite. Although the point of convergence appears to be solely dependent upon emission from a magnesium compound, the potential influence of the temperature of the flame upon the emitting species must not be disregarded.

(2) Hardy[4] describes the rules of color additive mixtures which state that all mixtures of two colors on the chromaticity diagram fall on the line drawn between those two colors. Johnson[5] suggests that by the application of these rules, the dominant wavelengths of non-halogenated colored flames can be adjusted. As illustrated in Figure 2, the results are dispersed along the line between the point of convergence of the three lines and the intercept with the perimeter of the chromaticity diagram. Thus, the observed behavior appears to respond in accordance with the rules of color additive mixtures using (a) the convergence point as a composite representation of magnesium compound emitter and temperature effect and (b) the intercept with the diagram perimeter as a representation of the dominant color emitter. For example, the yellow convergence line intercepts near 590 mμ which is the strongest emission line of atomic sodium. Therefore, it is proposed that all formulations of sodium and magnesium compounds will produce colors which fall between the convergence point and the perimeter intercept near 590 mμ.

(3) The information in Figure 2 for green flames is based

upon barium formulations and for red flames upon strontium. In a manner analogous to sodium, the barium-green flame colors are dispersed about the convergence line which intercepts at 524 mμ. Strong BaCl emissions have been reported at 524 mμ and for BaOH at 527mμ. In like manner, the strontium red flame colors show an intercept at about 640 mμ. Strong SrCl and SrOH emissions occur in this region. These observations tend to confirm the theory that (a) atomic sodium is the dominant emitter in yellow sodium flames, (b) BaCl and BaOH dominate in green barium flames, (c) SrCl and SrOH dominate in red strontium flames and that (d) colored flames based upon these metals will exhibit colors defined by the convergence line between the convergence point and the diagram perimeter intercept.

(4) The points on the chromaticity diagram which are grouped in the area of $x = .480$ and $y = .460$ were disregarded for purposes of locating the yellow line which converges with the green and red lines. Those readings were recorded about seven years ago from formulae substantially the same as the formulae represented by the points grouped about the yellow convergence line. Thus there was doubt concerning their validity. Because of this, samples with the same formulae were prepared to determine their chromatic values using the latest available techniques and equipment. Test of these new samples shows that the color falls on the yellow convergence line near $x = .520$ and $y = .406$. Thus the shift of the group of points around $x = .480$ and $y = .460$ away from the yellow

convergence line is attributed to instrumentation error.

5. SUMMARY

During the program, two relationships were observed. They are (a) that as the magnesium content in a sodium based flare increases, the excitation purity decreases and (b) that the chromaticity coordinates which represent a wide variety of sodium-yellow, barium-green and strontium-red flares when plotted on a chromaticity diagram appear to take the form of straight lines which converge toward a common point. The magnesium vs. purity relationship is interpreted to be the result of a magnesium compound formation or to be the result of changes in flame temperature or more likely a combination of these two possibilities. The color convergence and wavelength relationship is interpreted to suggest that (a) the convergence line between the convergence point and the diagram intercept will define all colors for a particular metal system, (b) that the convergence point is influenced by a metal emitter and flame temperature and (c) that the point of intercept represents the dominant emitting specie for that system.

6. VALIDITY

It is emphasized that the interpretations and suggestions advanced herein are not conclusions. Additional exploration of these phenomena will be required to provide more substantial evidence to support the generalizations. However, the observations are reported in an effort to stimulate the expression and extension of ideas related to this subject.

7. ACKNOWLEDGMENTS

The work was sponsored by the Bureau of Naval Weapons (RMMO-3). The observations and suggestions concerning additive mixtures by D. M. Johnson are gratefully acknowledged.

REFERENCES

1. Douda, B. E., Theory of Colored Flame Production, RDTN No. 71, R&D Department, U. S. Naval Ammunition Depot, Crane, Indiana, 20 March 64.

2. Barrow, R. F. and Caldin, E. F., Proc. Phys. Soc. London, B62, 32-39 (January 1949).

3. Douda, B. E., Emission Studies of Selected Pyrotechnic Flames, RDTN No. 77, R & D Department, U. S. Naval Ammunition Depot, Crane, Indiana, 4 August 64

4. Hardy, A. C., Handbook of Colorimetry, The Technology Press, MIT, Cambridge, 1936, p. 10.

5. Johnson, D. M., The Adjustment of Dominant Wavelengths in Non-Halogenated Colored Flares, RDTN No. 76, R & D Department, U. S. Naval Ammunition Depot, Crane, Indiana, 21 April 64.

DISTRIBUTION LIST

	Copies
Chief, Bureau of Naval Weapons Department of the Navy Washington 25, D. C.	1
Attention: Code DLI-31	1
Code DIS-3	1
Code RMMO-32	1
Administrator Defense Documentation Center for Scientific and Technical Information (DDC) Building No. 5, Cameron Station Alexandria, Virginia (22314)	20
Commander U. S. Naval Ordnance Test Station China Lake, California Attention: Code 4543	1
Library	1
Wright Patterson AFB Aeronautical Systems Division Dayton, Ohio Attention: ASRNCC-3	1
Commander U. S. Naval Ordnance Laboratory White Oak, Silver Spring, Maryland Attention: Code WE	1
Library	1
Commanding General U. S. Ordnance Corps Picatinny Arsenal Dover, New Jersey Attention: Pyrotechnic Laboratory	1
Arsenal Library	1
Unidynamics Universal Match Corporation 472 Paul Ave. St. Louis 35, Missouri Attention: Dr. Herbert Ellern	1

DISTRIBUTION LIST (Cont.)

	Copies
Denver Research Institute University of Denver P. O. Box 8786 Denver, Colorado 80210 Attention: Dr. Robert W. Evans, Mechanics Division	1
Institute for Research, CC1330 Frankford Arsenal Philadelphia, Pennsylvania Attention: Mr. Tom Stevenson	1
Engineering Design Handbook Office Duke University Box EM, Duke Station Durham, North Carolina Attention: Mr. G. Earl Rogers	1
Aerojet General Corporation Ordnance Research Divsion 11711 Woodruff Avenue Downey, California	1
Bermite Powder Company Saugus, California Attention: Mr. L LoFiego	1
Harvell-Kilgore Corporation Bolivar, Tennessee	1
Miller Research Laboratories 2832 Maisel Street Baltimore 30, Maryland	1
Pace Corporation 5607 Highway 61 South Memphis 2, Tennessee	1
Pyrotechnics Products Company Association Road Bellport, New York	1
U. S. Flare Division Atlantic Research Corporation 19701 Goodvale Road Saugus, California Attention: Mr. N. C. Eckert	1

DISTRIBUTION LIST (Cont.)

	Copies
Mr. Dell Lytle Special Devices, Inc. 16830 W. Placerita Canyon Road Newhall, California	1

Naval Ammunition Depot, Crane, Indiana
(RDTR No. 45)
RELATIONSHIPS OBSERVED IN COLORED FLAMES, by
Bernard E. Douda
25 September 1964 11p.

1. Flames, Colored
2. Flares, Colored
3. Emitters, Flame
4. Emission, Flame
5. Temperature, Flame

I. B. E. Douda

UNCLASSIFIED

Excitation purity of a sodium-yellow flame was observed to be a decreasing function of the magnesium content in the flare. The chromaticity coordinates representing a wide variety of sodium-yellow, barium-green and strontium-red flares when plotted on a chromaticity diagram appear to take the form of straight lines which converge toward a common point. Several theories are proposed to explain the observations, the convergence point and the intercept point of the convergence line with the chromaticity diagram perimeter.

UNCLASSIFIED

Naval Ammunition Depot, Crane, Indiana
(RDTR No. 45)
RELATIONSHIPS OBSERVED IN COLORED FLAMES, by
Bernard E. Douda
25 September 1964 11p.

1. Flames, Colored
2. Flares, Colored
3. Emitters, Flame
4. Emission, Flame
5. Temperature, Flame

I. B. E. Douda

UNCLASSIFIED

Excitation purity of a sodium-yellow flame was observed to be a decreasing function of the magnesium content in the flare. The chromaticity coordinates representing a wide variety of sodium-yellow, barium-green and strontium-red flares when plotted on a chromaticity diagram appear to take the form of straight lines which converge toward a common point. Several theories are proposed to explain the observations, the convergence point and the intercept point of the convergence line with the chromaticity diagram perimeter.

UNCLASSIFIED

Naval Ammunition Depot, Crane, Indiana
(RDTR No. 45)
RELATIONSHIPS OBSERVED IN COLORED FLAMES, by
Bernard E. Douda
25 September 1964 11p.

1. Flames, Colored
2. Flares, Colored
3. Emitters, Flame
4. Emission, Flame
5. Temperature, Flame

I. B. E. Douda

UNCLASSIFIED

Excitation purity of a sodium-yellow flame was observed to be a decreasing function of the magnesium content in the flare. The chromaticity coordinates representing a wide variety of sodium-yellow, barium-green and strontium-red flares when plotted on a chromaticity diagram appear to take the form of straight lines which converge toward a common point. Several theories are proposed to explain the observations, the convergence point and the inter cept point of the convergence line with the chromaticity diagram perimeter.

UNCLASSIFIED

Naval Ammunition Depot, Crane, Indiana
(RDTR No. 45)
RELATIONSHIPS OBSERVED IN COLORED FLAMES, by
Bernard E. Douda
25 September 1964 11p.

1. Flames, Colored
2. Flares, Colored
3. Emitters, Flame
4. Emission, Flame
5. Temperature, Flame

I. B. E. Douda

UNCLASSIFIED

Excitation purity of a sodium-yellow flame was observed to be a decreasing function of the magnesium content in the flare. The chromaticity coordinates representing a wide variety of sodium-yellow, barium-green and strontium-red flares when plotted on a chromaticity diagram appear to take the form of straight lines which converge toward a common point. Several theories are proposed to explain the observations, the convergence point and the intercept point of the convergence line with the chromaticity diagram perimeter.

UNCLASSIFIED